

Simulation on Collision of Magnetic Flux Tubes in the Quiet Solar Photosphere

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We investigate the collision of two parallel flux tubes for both cases of partial and complete magnetic reconnection. We find that when one flux tube with weak current and small radius collides with the other flux tube with strong current and large radius, the weak current flux tube splits into two small flux tubes through magnetic reconnection. We also find that when two magnetic flux tubes with weak current collide, there occurs strong fast magnetosonic wave emission, resulting in shock formation. While when two strong current loops collide, there is no strong wave emission. Secondary we investigate the collision of two non-collinear flux tubes with X-type configuration, taking into account of the effect of density inhomogeneity along the flux tubes due to the gravity. We find the strong upward plasma flows along the flux tubes and also shock wave emission from the X-type collision region. Finally we discuss the application of these simulation results to coronal heating.

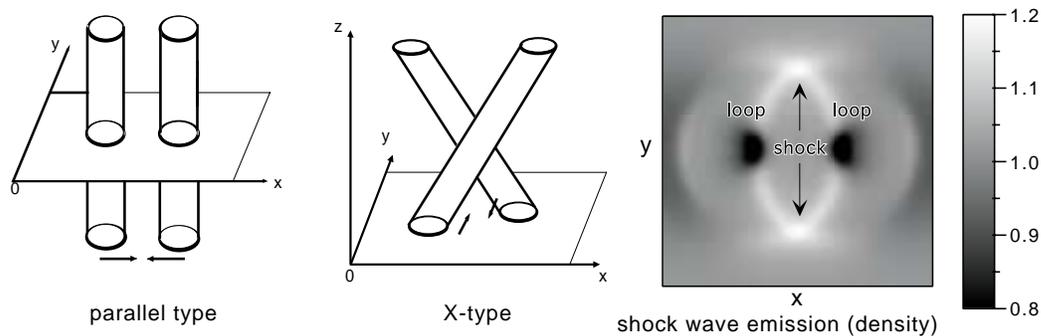


Fig.1 The right hand figure shows the density distribution in the x-y plane.

Simulation results and conclusion

In weakly ionized plasma near the photosphere, the magnetic field that is carried by ions can diffuse through the neutral gas. This process, which is known as ambipolar diffusion, can be described by a set of one-fluid model equations if the gas's ionization ratio is very low like $\rho_i/\rho_n = 10^{-2} - 10^{-3}$. We use a 3-D neutral-MHD code (Suzuki & Sakai (1996);¹⁾ Ryutova et al. (1998)²⁾). The system size for 2-D simulations is $0 \leq x \leq 4\pi L$, and $0 \leq y \leq 4\pi L$, while the system size in the z -direction for 3-D simulations is $0 \leq z \leq 4\pi L$. The mesh points N_x , N_y and N_z in the x -, y - and z -direction are $N_x = N_y = N_z = 80$, respectively. The time step is 0.005. The periodic boundary condition in the z -direction is used in 2-D simulations, while the free boundary conditions are used for all directions in 3-D simulations. The

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numerical schemes used here are the modified two-step Lax-Wendroff method, and implicit ADI method for solving the magnetic diffusion equation. The parameters we choose are ; $\beta = 1.0$, $R_m = 10^3$, $A_D = 10^{-3}$ ($A_D = \tau_A/\tau_c$: τ_A is Alfvén transit time and τ_c is collision time) and $\gamma = 5/3$. The two flux tubes have the same strength of magnetic field ($B_{z0} = 1$) along each tube. We take an initial magnetic fields (B_θ, B_z) and an initial density of flux tubes to satisfy an equilibrium.

We have presented simulation results of collision process of two magnetic flux tubes for both cases of parallel flux tubes and non-collinear tubes with X-type configuration. For two parallel flux tubes, we examined the condition for the fragmentation of magnetic flux tubes, by changing several parameters. It was found that when a strong current loop with large radius and a weak current loop with small radius collide each other, there occurs the fragmentation of the magnetic flux tube with weak current and small radius, while the strong current loop keeps to be unaffected during the collision. But the fragmentation process during the collision of two flux tubes is frequently observed in 3-D X-type collision. When weak current loops collide, strong magnetosonic waves are generated from the coalescence region and magnetosonic shock waves can be generated through the wave-wave interactions as seen in Fig. 1. About 60% of initial colliding kinetic energy of flux tubes is transformed to shock wave energy. The energy conversion rate to shock waves through flux tube collision is very effective. Therefore a question arises: what will happen, when the shock waves collide with surrounding other flux tubes? The answer on this problem is given by Sakai et al. (1999).³⁾

In a 3-D simulation with X-type configuration, we have taken into account of the effect of gravity, which can enhance the shock wave generation. One remarkable result due to gravity is that there appear strong upward (z -direction) plasma flows along the flux tubes as seen in Fig. 2. The kinetic energy transformed to the upper chromosphere and corona through the flux tubes exceeds the initial colliding kinetic energy, mostly due to the pressure enhancement near the region where magnetic reconnection takes place. Therefore the collision process of non-collinear flux tubes may play an important role for the coronal heating, basically from two points of view: (1) generation of strong shock waves, and (2) energy transformation by upward plasma flows along magnetic flux tubes. To understand more details, we need global 3-D simulations with more X-type configurations.

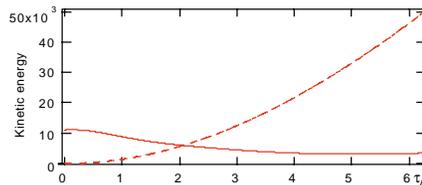


Fig.2 The time history of kinetic energy in the system: solid line shows kinetic energy of the y-direction and dashed line shows kinetic energy of the z-direction.

References

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- 3) J. I. Sakai et al., this issue.